

## BinHab: A Numerical Tool for the Calculation of S/P-Type Habitable Zones in Binary Systems

M. Cuntz, R. Bruntz

*Department of Physics, University of Texas at Arlington, Arlington, Texas, USA 76019; Email: cuntz@uta.edu, rbruntz@uta.edu*

**Abstract.** The aim of this contribution is to introduce the numerical tool *BinHab*, a publicly accessible code, available at The University of Texas at Arlington, that allows the calculation of S-type and P-type habitable zones of general binary systems.

### 1. Introduction

After several decades of research, planets in stellar binary systems now constitute a well-established observational result. Previous examples include P-type orbits, when the planet is found to orbit both binary components, as well as S-type orbits with the planet orbiting only one of the binary components with the second component acting as a perturber; see, e.g., Eggenberger et al. (2007) and Neuhäuser et al. (2007) for selected observational results and data.

Another topic of significant importance, especially concerning the astrobio-logical community, are studies of circumstellar and circumbinary habitability. Previous work focused on the traditional concept of Kasting et al. (1993) and subsequent studies, where habitability is defined based on the principal possibility that liquid water is able to exist on the surface of an Earth-type planet possessing a  $\text{CO}_2/\text{H}_2\text{O}/\text{N}_2$  atmosphere; for more sophisticated concepts see, e.g., Lammer et al. (2010), and references therein. Other relevant investigations concern studies of orbital stability, especially for (hypothetical) Earth-type planets in stellar habitable zones. This type of work has been pursued for single as well as multi-planetary and multi-stellar systems; see, e.g., Jones et al. (2001), Noble et al. (2002), Sándor et al. (2007), for early contributions as well as, e.g., Kane & Hinkel (2013) and Jaime et al. (2014) for more recent work. Some of these efforts resulted in stability catalogs of the habitable zones of the planetary systems known at the time.

Cuntz (2014a,b) [Paper I and II] forwarded a concise approach for the investigation of habitable regions in stellar binary systems, which forms the basis for *BinHab* (see Sect. 2). In Sect. 3, we will give applications to S/ST-type habitability for binaries of low mass stars. Our conclusions and outlook are presented in Sect. 4.

### 2. Description

## 2.1 Methods

The method as conveyed has previously been given in Paper I and II; thus in the following we will focus on the most decisive concepts, which include: (1) The consideration of a joint constraint comprising orbital stability and a habitable region for a putative system planet through the stellar radiative energy fluxes (“radiative habitable zone”; RHZ) needs to be met. (2) The treatment of conservative, general and extended zones of habitability for the various systems, referred to as CHZ, GHZ, and EHZ, respectively, following the approach given by Kasting et al. (1993) and subsequent work. (3) The providing of a combined formalism, based on solutions of a fourth-order polynomial, for the assessment of both S-type and P-type habitability. In particular, mathematical criteria are presented for which kind of system S-type and P-type habitability is realized.

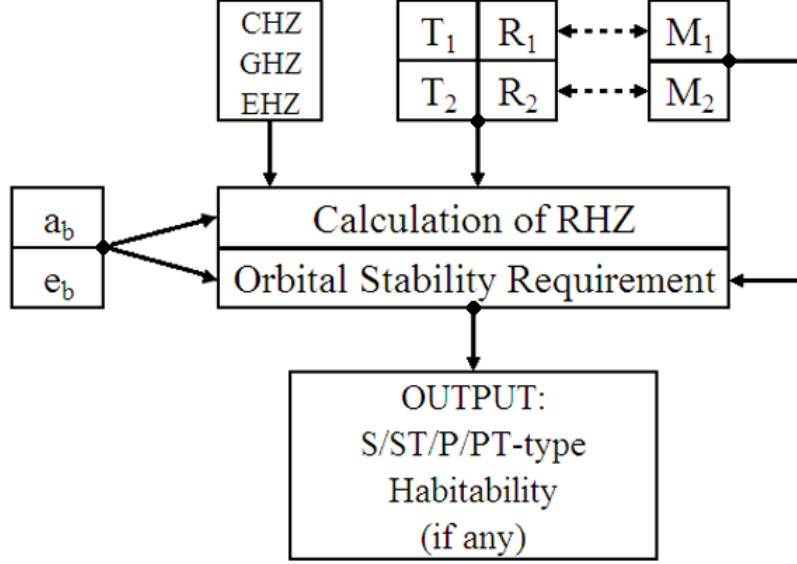
Following Paper I, five different cases of habitability are identified, which are: S-type and P-type habitability provided by the full extent of the RHZs; habitability, where the RHZs are truncated by the additional constraint of planetary orbital stability (referred to as ST and PT-type, respectively); and cases of no habitability at all. Regarding the treatment of planetary orbital stability, the formulae of Holman & Wiegert (1999) are utilized. **BinHab** is suitable for both circular and elliptical stellar binary components, the topic of Paper II. Figure 1 conveys the flow diagram. Note that for S-type orbits, the orbital stability criterion operates as an upper limit of orbital stability (see Sect. 3), whereas for P-type orbits, it operates as a lower limit of planetary orbital stability.

**BinHab** allows to consider general binary systems, including systems containing evolved stars. Surely, for main-sequence stars, there is an intimate coupling between the input parameter  $T_i$  and  $R_i$  ( $i = 1, 2$ ), the stellar effective temperature and radius, on the one hand, and  $M_i$ , the stellar mass, on the other hand, which is however not required for the usage of the code. The simulations of Paper I are largely based on data given in Gray (2005).

## 2.2 Implementation

To make **BinHab** publicly accessible, we created a website through which stellar system conditions could be entered, and the equations pertinent to **BinHab** would then be used to find whether any habitable zone or zones exist, and if so, what type. A virtual server was set up and hosted by the UT Arlington IT department at <http://physbinhab.uta.edu>, as a dedicated server for the **BinHab** website. It allows the user to enter binary system parameters (i.e., semi-major axis and eccentricity), separate stellar parameters for the two stars (i.e., temperature, luminosity, and mass), and the type of habitable zone the user would like to look for (i.e., CHZ, GHZ, or EHZ). Background information on the different types of habitable zones is also given.

The output states whether there were any habitable zones found, and if so, what type (S, ST, P, or PT) and the inner and outer limit of any zones. The website itself uses HTML (HyperText Markup Language) to interface with the user, by displaying information, accepting user input parameters, and displaying the results of the **BinHab** calculations. The user’s input is passed to PHP (PHP: Hypertext Preprocessor) code, which also checks the validity of the input. If any of the parameters are out of range, the PHP code creates a warning message, which is passed to the HTML code and displayed to the user, explaining what needs to be adjusted. If all parameters are acceptable, the PHP code saves them

Figure 1.: *Flow diagram of BinHab*

to a new input file, runs the **BinHab** Fortran binary on the input file, and collects the output from the binary. The output is then checked, formatted, and passed to the HTML code, for display to the user.

The use of PHP allows for much more processing of the input than is possible with HTML alone and is necessary for running the Fortran binary. Fortran is used for implementing the **BinHab** algorithms, rather than PHP, for a variety of reasons, including that it is much more widely used in the scientific community and that as a compiled language, it executes much faster than the interpreted PHP code. Additionally, the Fortran code and input files are stored in a segment of the server directory structure that is inaccessible to the website, but accessible to the PHP code. Hence, the Fortran code is not viewable or downloadable from the web, as it can only be accessed by the PHP code, which runs on the server, and therefore is not directly viewable from the Internet. In order to make the website easier to find, we successfully submitted the URL to the two largest search engines: Google and Bing (which also drives the Yahoo! search engine).

### 3. Example: Application to S/ST-Type Habitability for Binaries of Low-Mass Main-Sequence Stars

In order to illustrate the capacity of the method, we convey studies of S/ST-type habitability for binaries of low-mass main-sequence stars. Here we focus on stars of masses  $0.75 M_{\odot}$ ,  $0.65 M_{\odot}$ , and  $0.50 M_{\odot}$ , corresponding to spectral types of K2V, K6V, and M0V. This type of work is motivated by the observational finding that stars with masses below about  $0.8 M_{\odot}$  constitute nearly 90% of all stars in

the Milky Way (e.g., Kroupa, 2002; Chabrier, 2003). As an example we focus on S-type and ST-type habitable zones in binaries consisting of these types of stars. In particular, we investigate the role of the eccentricity of the binary system  $e_b$  on the width of the S/ST-type habitable zones (if existing) for systems with  $2a_b = 5.0$  AU as examples while focusing on results for the GHZ (see Fig. 2).

The following aspects are identified: For all stellar mass combinations, stellar habitable zones are found for eccentricities below 0.20. For the majority of models pursued, S-type habitability is truncated due to the orbital stability requirement of the putative planet resulting in ST habitability classification (see Table 1). Stellar pairs with masses of  $0.75 M_\odot$  exhibit the broadest RHZs due to their relatively high luminosities; however, in this case the relatively large stellar masses lead to a significant truncation of circumstellar habitability, resulting in relatively narrow habitable zones. On the other hand, stellar pairs with masses of  $0.50 M_\odot$  show S/ST-type habitable regions up to binary eccentricities of 0.65 (see Table 2), albeit the widths of the habitable zone are relatively small compared to other primary–secondary mass combinations, especially for cases of small binary eccentricities. Starting at a well-defined eccentricity, the width of the habitable zones decreases linearly as a fraction of the binary eccentricity for all mass combinations, encompassing both systems of equal and nonequal stellar masses, owing to the truncation criterion (Holman & Wiegert, 1999). Consistently smaller widths for the habitable regions are identified for models based on CHZs relative to GHZs, as expected.

Table 1.: *S/ST-type Habitability for Models of  $2a_b = 5.0$  AU, GHZ*

Model	0.0	0.1	0.2	0.3	0.4	0.5	0.6
$M_1 = 0.75 M_\odot, M_2 = 0.75 M_\odot$	ST	ST	ST	...	...	...	...
$M_1 = 0.75 M_\odot, M_2 = 0.65 M_\odot$	ST	ST	ST	...	...	...	...
$M_1 = 0.75 M_\odot, M_2 = 0.50 M_\odot$	ST	ST	ST	...	...	...	...
$M_1 = 0.65 M_\odot, M_2 = 0.60 M_\odot$	S	ST	ST	ST	ST	...	...
$M_1 = 0.65 M_\odot, M_2 = 0.50 M_\odot$	S	ST	ST	ST	ST	ST	...
$M_1 = 0.50 M_\odot, M_2 = 0.50 M_\odot$	S	S	S	S	ST	ST	ST

Table 2.: *Critical Values of  $e_b$  for S/ST-type Habitability*

Model	CHZ	GHZ
$M_1 = 0.75 M_\odot, M_2 = 0.75 M_\odot$	0.12	0.20
$M_1 = 0.75 M_\odot, M_2 = 0.65 M_\odot$	0.15	0.23
$M_1 = 0.75 M_\odot, M_2 = 0.50 M_\odot$	0.19	0.27
$M_1 = 0.65 M_\odot, M_2 = 0.60 M_\odot$	0.43	0.48
$M_1 = 0.65 M_\odot, M_2 = 0.50 M_\odot$	0.46	0.51
$M_1 = 0.50 M_\odot, M_2 = 0.50 M_\odot$	0.62	0.65

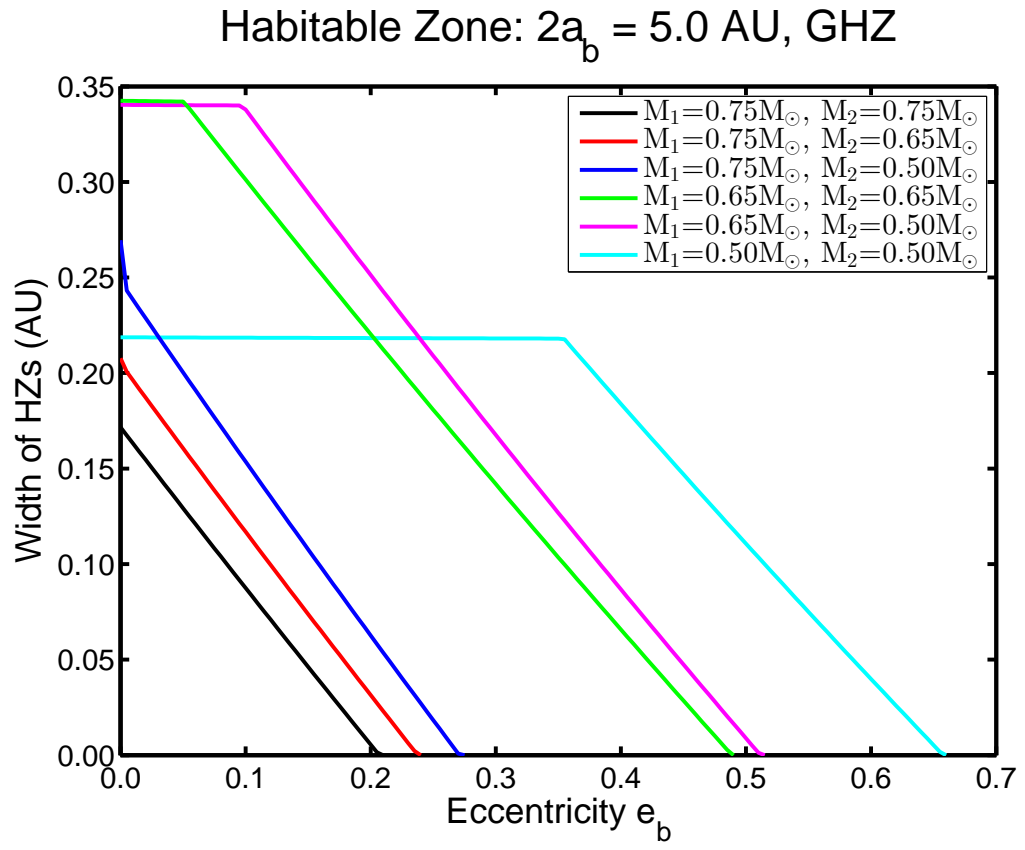


Figure 2.: Widths of *S/ST-type* habitable zones in low-mass binary systems.

#### 4. Conclusions and Outlook

We provided a short description of the features and capacities of the numerical tool **BinHab** hosted at The University of Texas at Arlington. It considers a joint constraint including orbital stability and a habitable region for a putative system planet through the stellar radiative energy fluxes, among various other desirable features. Although the code has previously mostly been used to investigate binary systems consisting of main-sequence stars Cuntz (2014a,b), it is highly flexible; it can also be utilized for the calculation of habitable zones for systems containing a subgiant, giant, or supergiant. Concerning the latter, **BinHab** has already been used to study the habitability of Earth-mass planets and moons in the Kepler-16 system (Quarles et al., 2012), known to host a circumbinary Saturn-mass planet. Ultimately, it is our goal to expand the developed methods to multiple stellar systems, which are of notable interest to the scientific community.

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